GE Aviation: Investing in the Future

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imagination at work

2nd Meeting of the Committee on Globalization of Science and Technology: Opportunities and Challenges for the Department of Defense

The three questions:

(a) How GE maintains global awareness of what is happening in diverse areas of science, technology, and innovation?

(b) How GE builds mutually beneficial relationships and partnerships across the global S&T enterprise?

(c) How GE assesses the benefits and costs of conducting, as well as engaging in, global S&T?

Note: The material that follows is a high level, non-proprietary response by the General Electric Company to the aforementioned questions.

GE Aviation:

Legacy/marketplace

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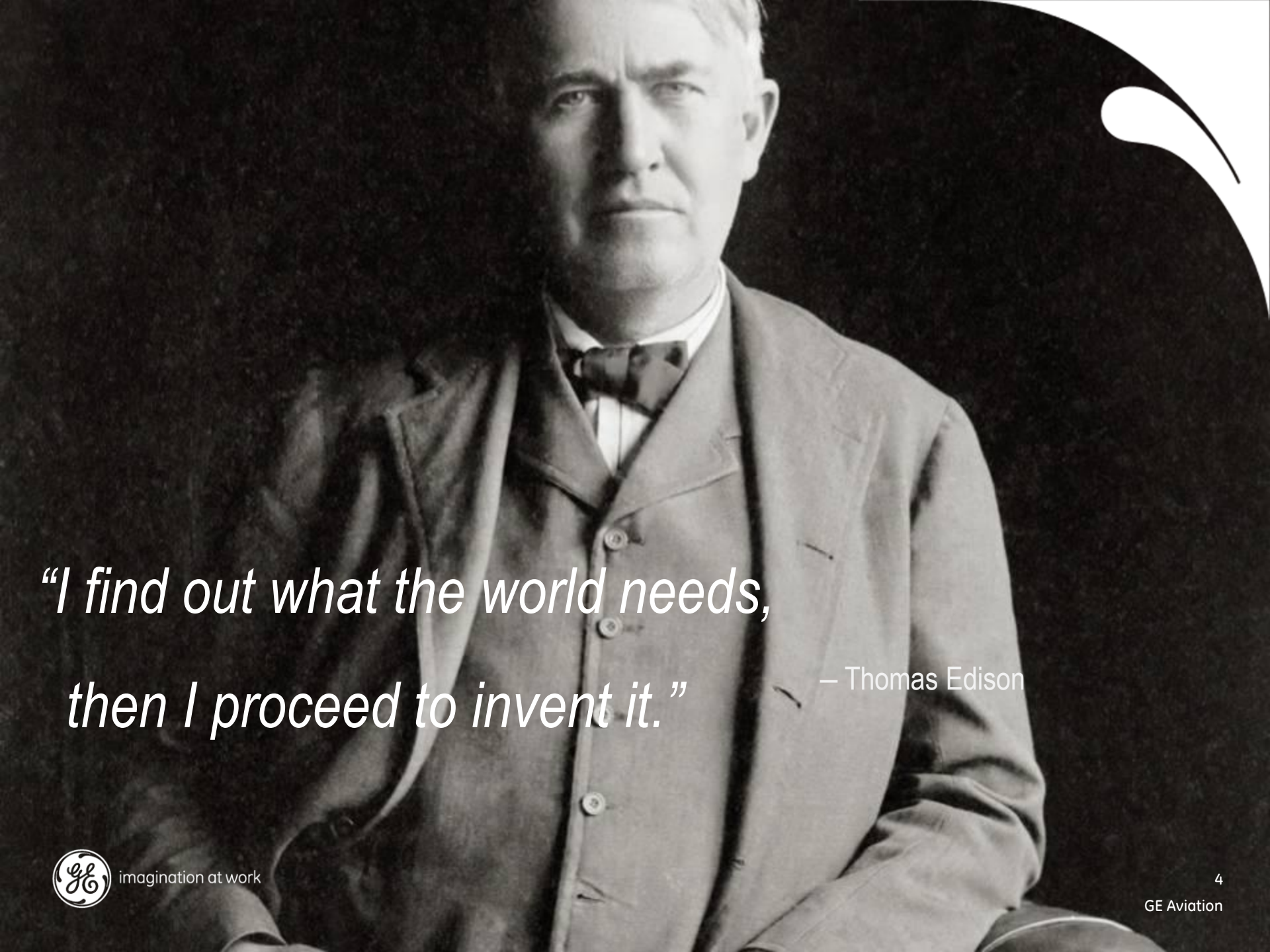

"I find out what the world needs,
then I proceed to invent it."
– Thomas Edison

GE Aviation portfolio … $20B

Commercial engines $6.1[-a)]

Commercial engine services $7.0[-a)]

Military engines and services $3.9[-a)]

Systems $2.7

Business and general aviation/other $0.4

Largest provider of jet engines in the world

- 40,000 employees
- ~85 sites globally

(a- Includes GE's share of revenue from CFM and EA engines
CFM is a 50/50 JV between GE and Snecma
EA is a 50/50 JV between GE and Pratt & Whitney

Technical **innovation** …

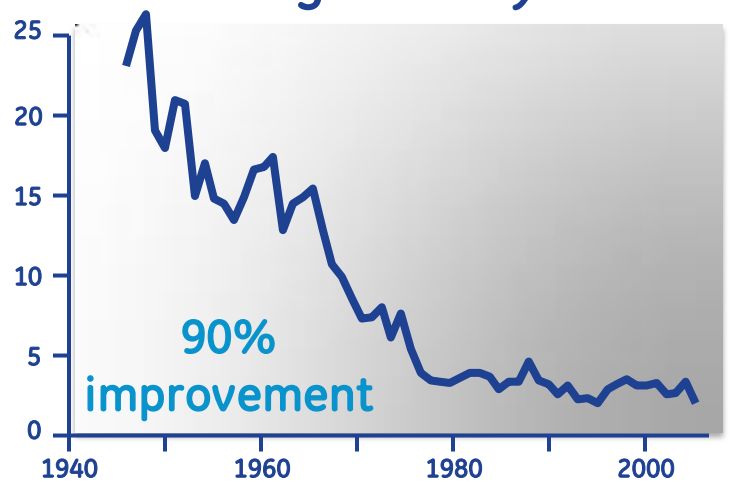
Key to our past and future

First

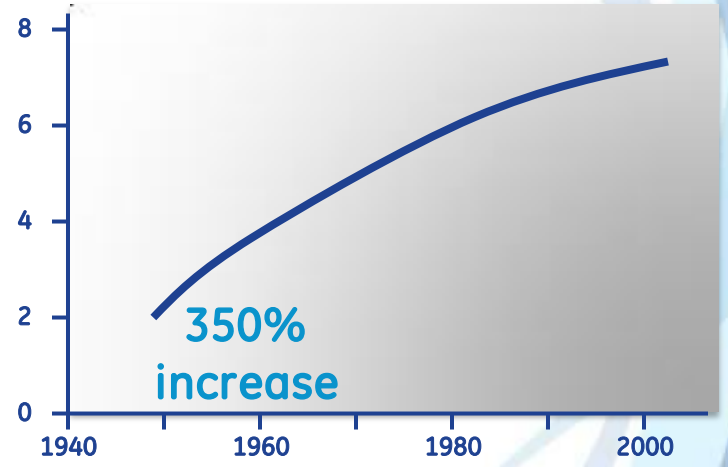
- U.S. jet engine
- U.S. turboprop engine
- Mach 2 engine
- High bypass engine
- Variable cycle turbofan engine
- Unducted fan engine
- Composite fan blade in airline service
- 120,000+ lb thrust engine
- 4D trajectory flight in revenue service
- Modular power tile
- FMS-controlled Unmanned Aircraft System

50 years of engine improvements

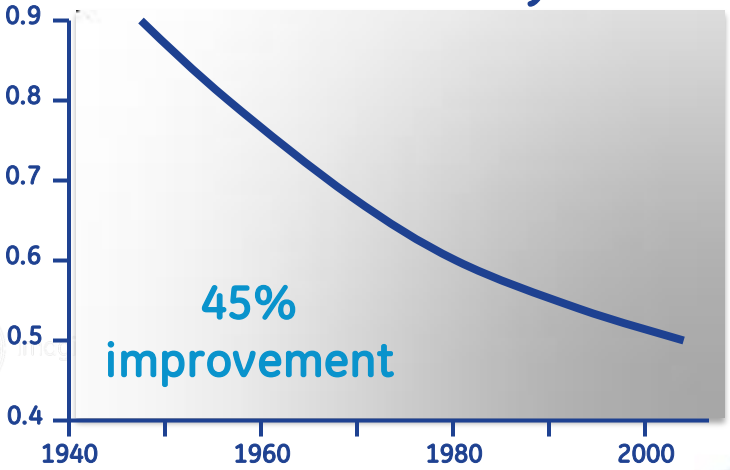
Flight Safety



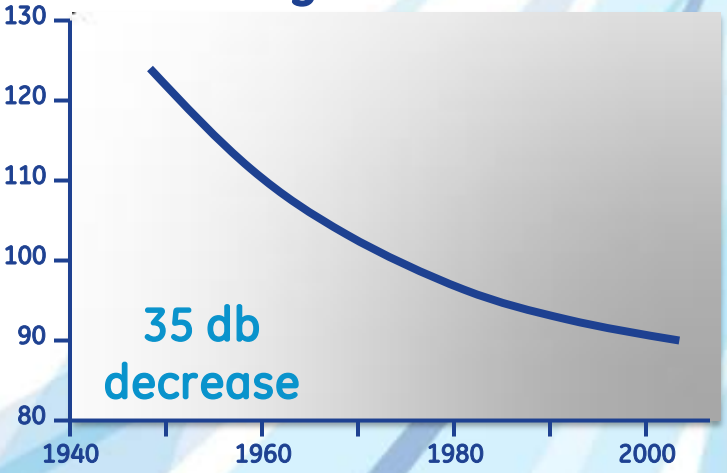
Thrust to Weight



Fuel Efficiency



Engine Noise



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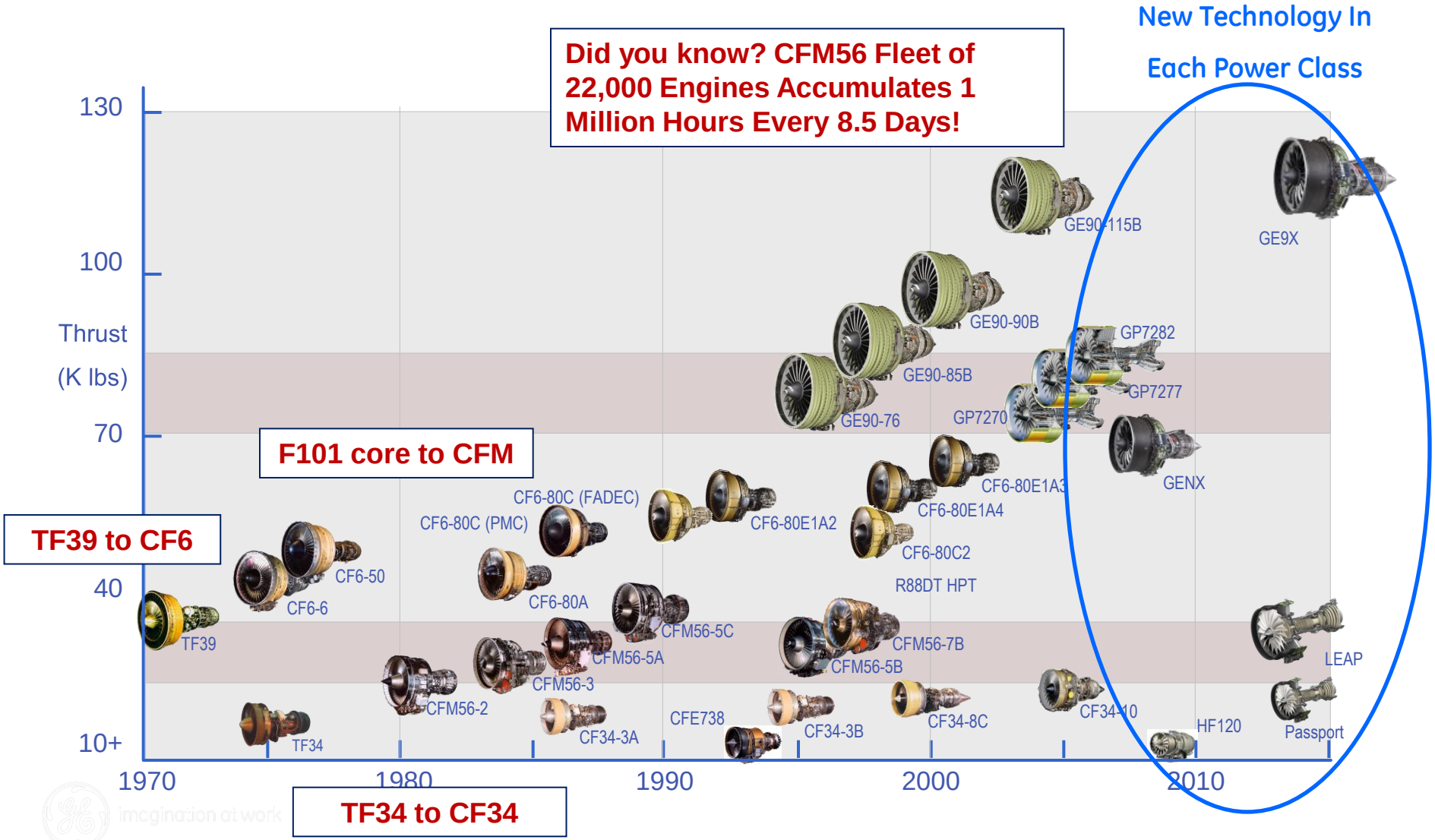
Commercial engines…by thrust rating



World's Broadest, Most Modern Product Line Leveraged Military Heritage

The Future:

Global forces/environment

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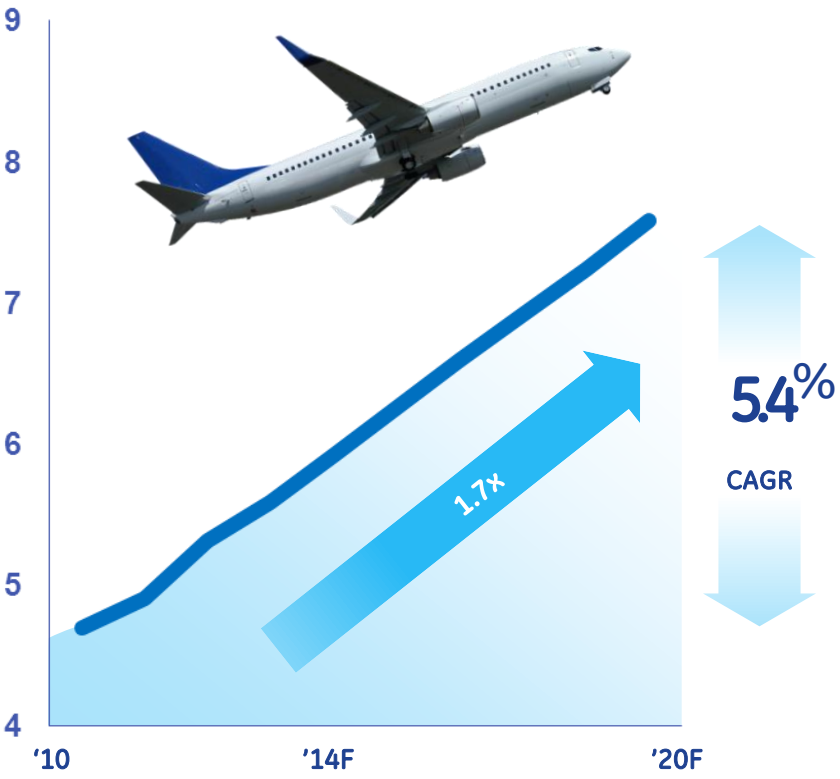
Commercial aviation growing steadily

Airframe	Production rate ('12 → '14)	
A380	2.7 → 3.5	GP
777	7 → 8.3	GE90
787	3.5 → 10	GEnx
737	38 → 42	CFM
A320	40 → 42	CFM
EJet	8.7 → 9.2	CF34
CRJ	2.5 → 2.5	CF34

9.3% CAGR

Traffic growth (Trillion RPKs)



Highest production ramp rates in 3 decades … inconsistent with demand growth

Boeing and Airbus are increasing rates to ~40 / month. That means: 40 x 2 (Airbus & Boeing) x 11.5 mth. / yr. = 920 / yr. or ~1,000 including the other new single aisles.1,000 x 5 years = 5,000 / 10 yrs. = 10,000 / 20 yrs. = 20,000 aircraft.

Our Industry-Specifically Propulsion

- Timescales of innovation long…safety demands technologies to be proven…strategic vision/commitment a must (Gamma TiAl, CMC, etc.)…multi-decade VISION
- Almost every flying technology started as a USG funded (NASA, DoD, etc.) early TRL level study, many driven to TRL 5 or 6. Changing dynamics/players…WTO agreement, sequestration, emerging funding sources
- Doubling of revenue miles every 13-15 years despite "shocks" such as 911
- Question: How many "tube/wing" iterations are left?
  - 15% campaign/campaign FB improvement a must
  - ICAO 2050 CO_2 commitment, other regs looming

Technology Readiness to Serve Today and Tomorrow

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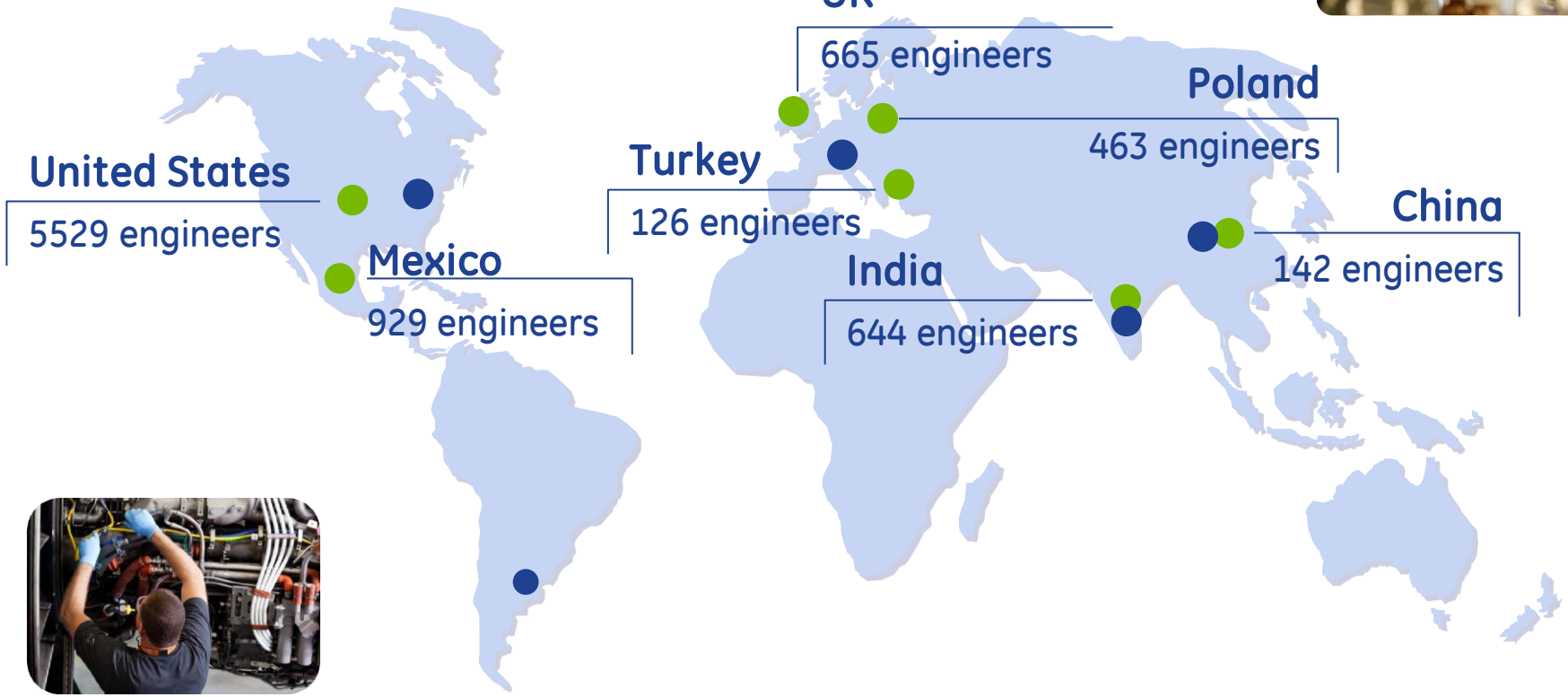
GE Aviation Engineering



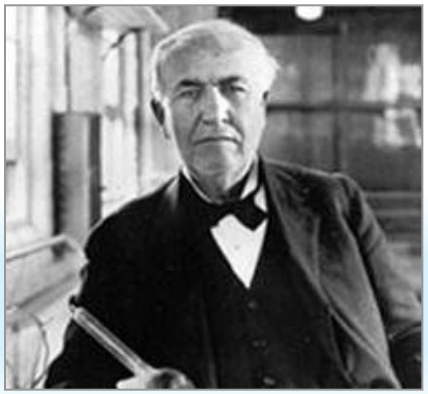
Over 8000 engineers around the globe
3000 technologists at 5 Global Research Sites

Practical innovation … GE's model

Global resources teamed to advance technology

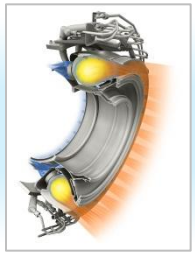
Idea creation + **Technology maturation** = **Winning products**

- Internal
- Customers
- Government
- Universities (300+ relationships)



- Cross-disciplinary teams
- Technology roadmaps
- TRL/MRL maturation plans
- Long-term growth strategies
- Tactical funding

- 30+ new technologies by 2020



The Physics of "Readiness to Serve"

$$Range = \left(\frac{V_0}{SFC}\right) * \left(\frac{L}{D}\right) * \ln\left(\frac{W_{initial}}{W_{final}}\right)$$

$$= \left(FHV * \eta_{thermal} * \eta_{transfer} * \eta_{propulsive}\right) * \left(\frac{L}{D}\right) * \ln\left(1 + \frac{W_{fuel}}{W_{payload} + W_{empty}}\right)$$

	$\eta_{thermal}$	$\eta_{transfer}$	$\eta_{propulsive}$	W_{empty}
Today	• Highly Loaded Compressors • High OPR Low Emissions Combustors	• Low Loss Inlets • Variable Low Loss Exhausts	• Very High BPR Turbofans • Ultra High BPR Turbofans	• Novel Alloys / MMC's • Non-metallics
2020-2050?	• Adaptive cycles • Constant Volume Combustion • Hybrid Electric Propulsion	• Distributed Power Transmission	• Open Rotors • Distributed Propulsion • Wake Ingestion	• Advanced Engine Architectures

Essential technologies … keeping the pipeline filled

Technology

Composites

Lean combustion

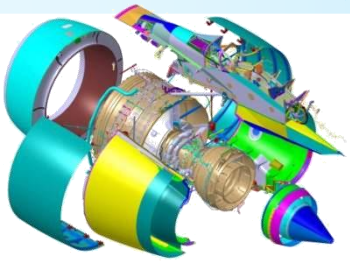
Advanced cooling

High-temp materials

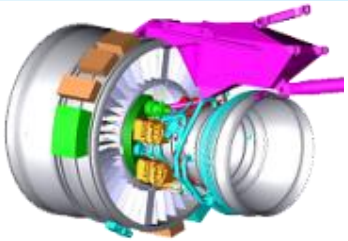
Flight Management

2010 → Advanced turbofan → Integrated engine and aircraft systems → Adaptive cycles; Advanced architectures → **2020**

Architecture

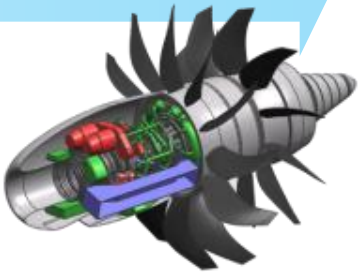


Integrated propulsion



Integrated power generation

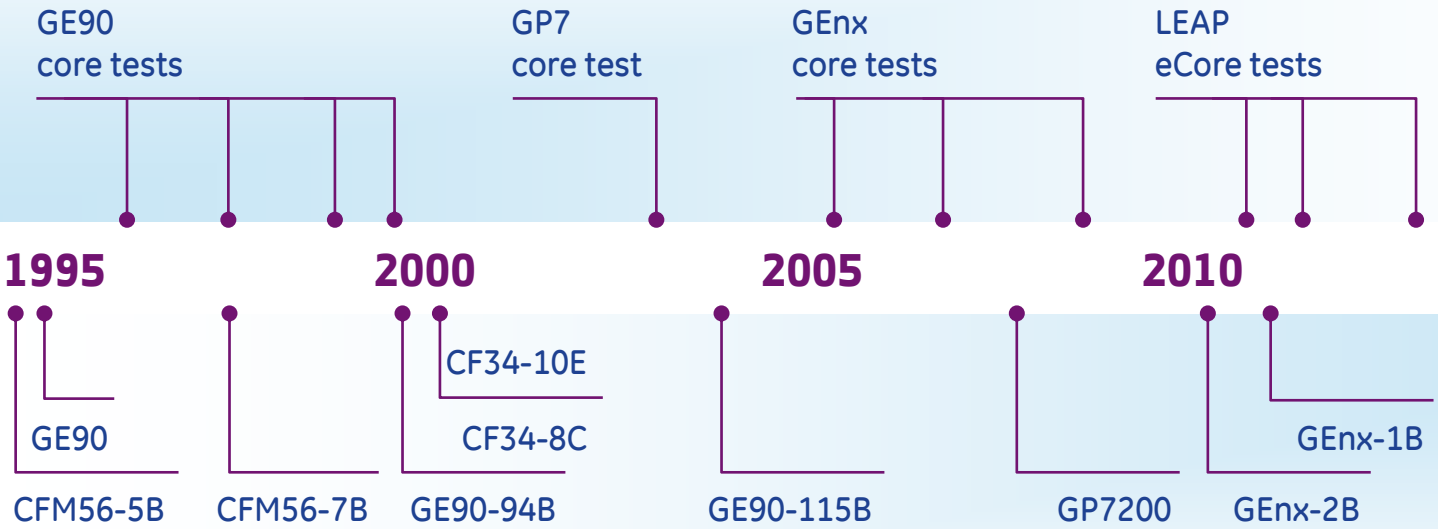
Core efficiency



New designs

Technology success takes commitment and opportunity

Commitment … **$1-2 billion** continuous technology investment per year, despite 911 (01), SARS (02), Avian Flu (05), and financial meltdown (08)



Opportunity … **10 new engines** proving and maturing technology

Propulsion R&D and/or S&T:
2005 to date, one of the best of times…what follows?

DARPA: VULCAN

EU: Clean Sky JTI (€1.6 B)

FAA: CLEEN, NextGen

NASA: ERA, Low NOx, N+1, N+2, N+3, RTAPS, SMAAART, etc.

VAATE: AATE, ADVENT, AETD, FATE, HEETE, VCAT, etc

SBIRs: Numerous Opportunities

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Background courtesy of NASA

VAATE Propulsion Demo Programs
Despite F136 loss, helps GE preserve industrial base

	GE	Other OEM	Other OEM Team	Other OEM
AATE (USA)	Win		Win	
ADVENT (USAF)	Win	Win		
AETD (USAF)	Win			Win
FATE (USA)	Win			
HEETE (USAF)	Win	Win		
Total Wins	5	2	1	1

NextGen portfolio
Potential military/commercial technology synergies

	AATE (Advanced Affordable Turbine Engine)	FATE (Future Affordable Turbine Engine)	ADVENT (Adaptive Versatile Engine Technology)	HEETE (Highly Efficient, Embedded Turbine Engine)
				
Customer	US Army	US Army	US Navy/ US Air Force	US Air Force
Program goals	25% better SFC 65% ↑hp/wt	35% better SFC 80% ↑hp/wt	20-200+% better SFC	35% better SFC
Technologies	3D aero, materials	3D aero, efficiency	Variable cycle, 3D aero, FLADE™	3D aero, efficiency
Segments	Attack/utility Helicopters	Heavy lift Helicopters	Combat aircraft	Tanker/Transport


Blackhawk


NextGen heavy lift


6th Generation


KC-135

Technology demonstrator programs

Renewing our technology DNA for new products and upgrades of fielded products. Mostly USG funded, what comes next?

Global S&T relationships and partnerships

Emerging architectures, new thermodynamic cycles, hybrids, etc., concept studies good, but…cannot let others get there first!

- Organic capability never enough…build portfolio to meet the future via several approaches:
  - ✓ Joint Technology Development Agreements (JTDAs)
    - Example: Meltless Ti
  - ✓ Joint Ventures
    - Example: TAPS one piece fuel nozzle
  - ✓ Business Development (BD) plays…acquisition
    - Example: Additive manufacturing
- Must participate in setting standards for the certification of emerging technologies:
  - ✓ EU sent out draft electric cert rules for light sport aircraft in 2012 for comments, establish rules in 2013.

S&T value proposition…key items

Emerging global players, significant inducements from non-traditional sources:

- Canada (>48% R&D reimbursements), China (significant FTZ inducements, seeking partnerships), EU (Clean Sky I and II), and Singapore (A*STAR)…can offset high costs of TRL/MRL maturation of emerging technologies
- Background & new IP release requirements a key decision driver (Appears to be a key part of future DoD acquisition requirements)
- Campaigns and proposals for our products…linked to technology engagement/sharing

GE's commitment …

- Technology innovation for customer value
- Learning from the world's largest installed fleet
- Focusing on people, processes, and tools across the globe
- To be prepared for, and shape, the future of flight

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